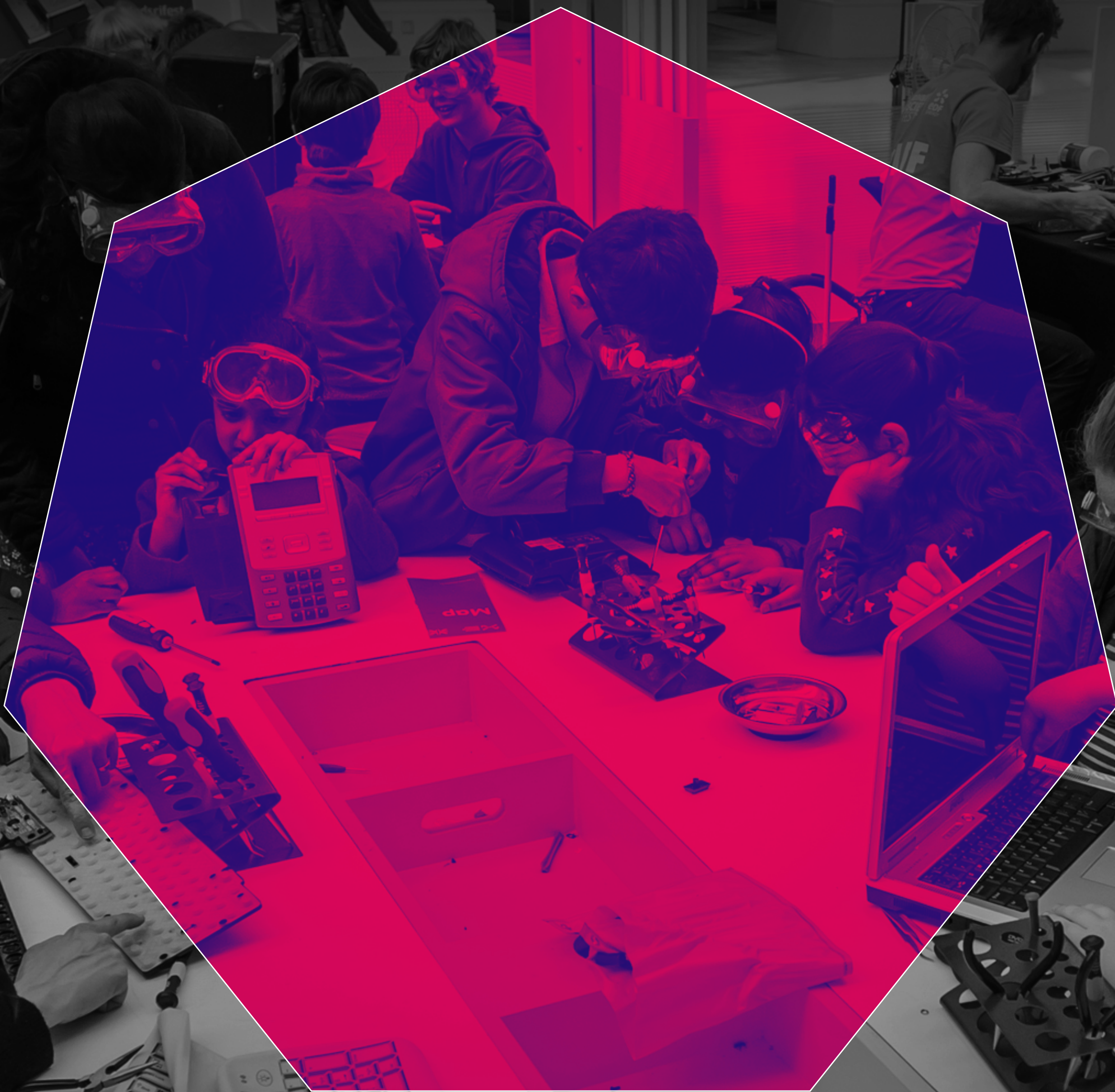
Royal Academy of Engineering

MANCHESTER 1824
The University of Manchester



Progressing to be an Engineer

By Dr Lynne Bianchi, Julie Wiskow, Dr Jonathan Chippindall and Dr Amy Bonsall

Science & Engineering Education Research and Innovation Hub,
The University of Manchester

Progressing to be an engineer is inspired by a passion to give more primary children a positive experience learning engineering in school. It builds on the *Tinkering for Learning* report and pedagogy published in 2018, and is written for teachers and STEM educators.

What's this report about?

This report focuses on the way in which engineering can be taught within the primary mainstream curriculum. It provides detail of a research study that builds upon the six Engineering Habits of Mind (EHoM, Lucas et al, 2014) and the principles and approaches for developing engineering in primary classrooms (Bianchi & Chippindall, 2016, 2018).

Specific focus is paid to progression and how children's learning of engineering habits of mind and skills can be developed from 5- to 7-year-olds (Key Stage 1 in England) and 7- to 11-year-olds (Key Stage 2). This report has resulted in the creation and trialling of a draft Engineering Learning Progression Framework for primary schools.

The Engineering Learning Progression Framework applies and builds on three key elements: the Engineering Habits of Mind; the Engineering Design Process and aspects of Primary Design and Technology National Curriculum (DfE 2014). It is informed by literature published about this area of work, in particular the *Next Generation Science Standards* (NGSS), Massachusetts Science and Technology/Engineering Curriculum 2016 (Mass. STE) and *Engineering is Elementary* (EiE) from the Museum of Science (Boston).

By working with teachers, the framework has been trialled in classrooms. Five case studies exemplify how lessons have been taught alongside examples of children's learning. We acknowledge that much more work still needs to be done to trial how the framework supports teachers in planning engineering lessons and the way they give feedback to children on their next steps in learning.

Why is this important?

Since 2014, the Science & Engineering Education Research and Innovation Hub (SEERIH) has developed a programme of research and teacher professional learning focused specifically on engineering education in primary schools. As part of a wider mission to close the opportunity gap for children in science and engineering, SEERIH has collaborated with the Royal Academy of Engineering (the Academy) and the Centre for Real World Learning. The design of teaching and learning approaches that enable engineering education to thrive within mainstream primary schools has been central to our mission.

Engineering is not a subject in the primary curriculum for England. Curriculum policy changes in Wales and Scotland have seen engineering being made more explicit. For example, one of the six Science and Technology statements in Wales states: **"Design thinking and engineering offer technical and creative ways to meet society's needs and wants"**

Progression steps are provided for teachers to use, and although these steps are not intended to be used as age-related judgements, they describe learning expectations that develop across the primary and secondary age phases)[1]. This is an important step forward for our mission, and supports our drive to make explicit how engineering skills and knowledge can be developed in the primary years and how that can be made progressive.

Having already begun to address key questions in this area (**Figure 1**), this report seeks to answer the question: **How do we know children are getting better at thinking and working as engineers?** The report will have a key focus on how we progress and monitor children's engineering development in the primary classroom when learning is embedded in current curriculum requirements. We have worked with teachers to describe and exemplify this in practice, which maps to design technology and science requirements and gives authentic links to literacy and history.

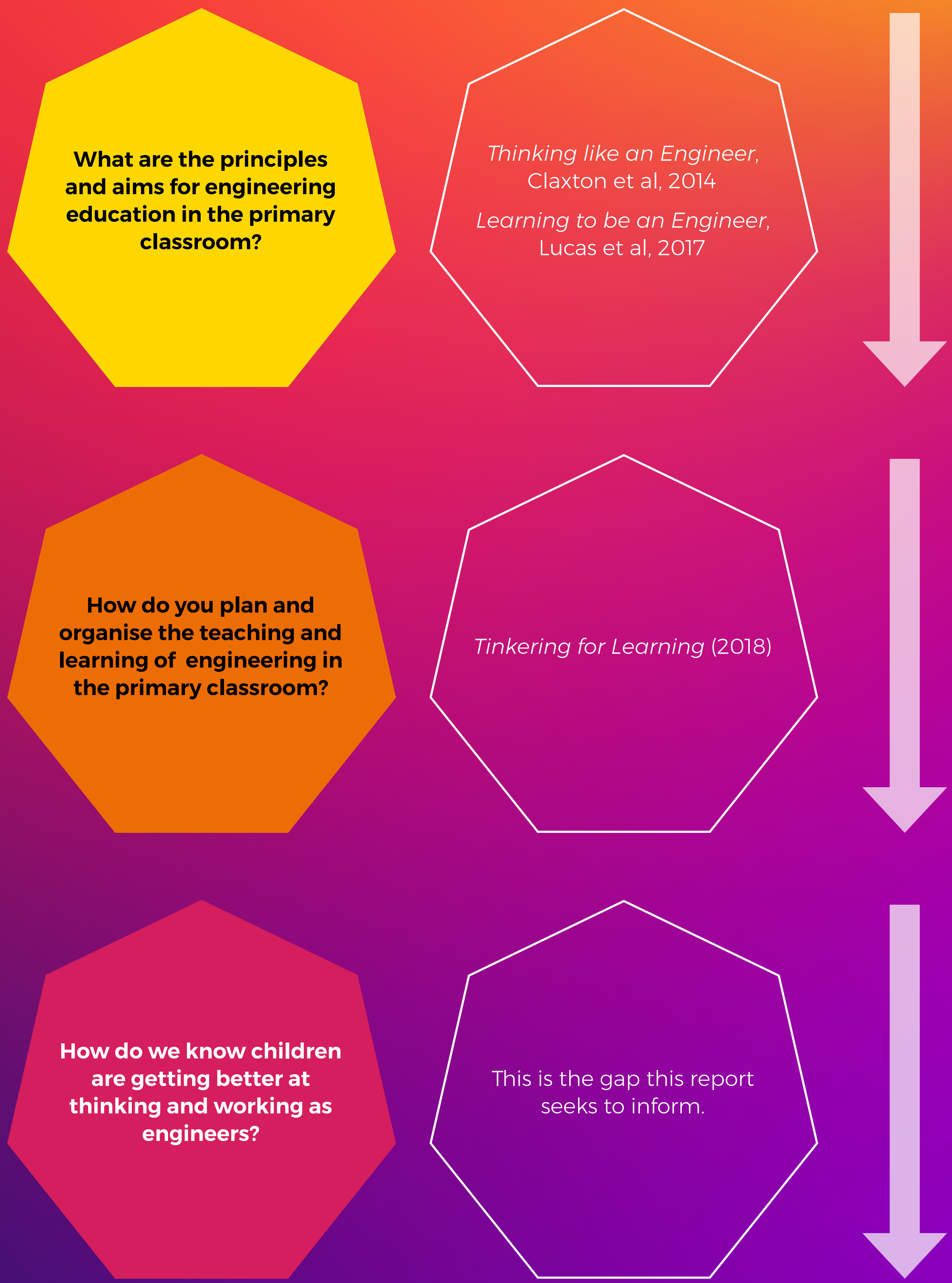
Many questions arise when we tackle this area of interest, including:

- How can engineering achievement be described across the primary years?
- How does this affect the planning and feedback on learning for a child?
- How do existing engineering activities for primary pupils support progression?
- What support do teachers need to gain confidence and experience with engineering in primary classrooms?
- What are the knock-on implications for transition? What information should be shared between year groups and between schools about children's engineering abilities?

We have sought in this study to develop a learning progression framework for engineering from age 5 to 11 to inform dialogue and debate. We have drawn on literature and consultation with specialist and teacher groups, and devised and trialled lessons to review early ideas.

1 https://hwb.gov.wales/curriculum-for-wales/science-and-technology/descriptions-of-learning/

Figure 1:
Establishing engineering education in primary classrooms



What is a learning progression?

An engineering learning progression (ELP) can provide support for planning teaching, however it will never offer a definitive pathway of progression for all children. We know that it will stimulate greater attention and thought around the learning outcomes that we aspire to for children. The challenge, however, is that due to the different contexts, learner characteristics and opportunities, a progression framework is neither obvious nor simple to develop.

A number of terms are used to describe tools that set out expected paths in progression of learning, for example learning ladders, progression pathways and learning trajectories. While there may be subtle differences between approaches, the broad aim is the same, namely to linearise learning in a subject to provide guidance on what is taught first, second and so on. They enable us to evaluate whether children have achieved what we hoped they would for their age or stage and they tell us what to plan to teach next or plan to return to if there are gaps in learners' prior learning.

Progression tools such as these exist in different guises for most subjects, since they form the backbone of sequencing lesson plans in schemes of work and schools' curricular. The challenge for engineering education at primary school is that it has never been defined as a curriculum subject in England, nor in many other countries across the world. It is this gap that this research focused on, with the aim of proposing ideas and options to plug the gap through the development of an ELP framework for children between 5 and 11 years.

Three frameworks were selected as the underpinning reference material to draft the new ELP, together with literature from a wider scoping review (Bonsall et al, 2020). They were chosen because they described aspects of progression in children's development in engineering, their taxonomy of skills reflected the Engineering Habits of Mind or Engineering Design Process, or they encompassed criteria or descriptors – for example part of an existing curriculum identified as having learning progressions that offered descriptors for primary-aged pupils. These included:

- Next Generation Science Standards (NGSS)
- Massachusetts Science and Technology/ Engineering Curriculum 2016 (Mass.STE)
- Engineering is Elementary (EiE) from the Museum of Science, Boston.

How have we gone about achieving it? *The research approach*

There were four phases of research, including consultation and collaboration with teachers and specialist STEM educators (**Figure 2**).

Literature search

Aim: to systematically review existing learning progressions for engineering across primary- and secondary-related age groups worldwide

A purposeful scoping review was undertaken to locate any documentation that related to a learning progression in engineering. This was to identify existing material that described features of progression in engineering education at primary or secondary school level. The search drew on academic papers and reports from across the world, although was limited to papers written in the English language and from 2010 to present day. The full details of the search are published in Bonsall et al (2020)[2].

STEM specialist consultations

Aim: to be informed and guided by specialist STEM educators

A group of specialist STEM educators included engineering and education academics from the University of Manchester; industry engineers; design technology, science and computing education consultants; and primary and secondary teachers with previous experience of engineering projects. Discussions and feedback on the research ideas led to the refinement of the ELP, in particular with regard to the way children's progression in engineering thinking and skills was described. The nature of progression and how the framework linked to the Engineering Habits of Mind and Engineering Design cycle were all considered.

Teacher development group

Aim: to write and review the learning progression, designing and trialling lessons

A group of teachers from Greater Manchester schools supported the writing of the learning progression. Lessons were co-created and trialled, which sought to 'validate' the progression objectives (Bianchi 2017). Teachers worked in pairs, taking different descriptors and considered topics or themes that aligned to subject areas including history or science. Children's work was collected to demonstrate the children's learning, where they had difficulty or where the lesson or descriptor needed refinement.

Desk-work

Aim: to review literature and collate insights and evidence from lesson trials

Over the course of the project, an iterative development of the learning progression allowed for insights to refine the framework. These were reviewed within the team, with the STEM educators and the teacher group.

Figure 2: Continual development of the learning progression framework

2 Bonsall. A, Bianchi. L, and Hansen. J, (2020) *A scoping literature review of learning progressions of engineering education at primary and secondary school level, paper currently under review,* Journal of Research in Science & Technology Education

What does the ELP look like?

The findings from the research are reported in this section and include the ELP framework for 5- to 11-year-olds and case studies from school-based trialling, which includes evidence of children's learning.

The ELP framework provides a series of developmental descriptors for children of 5 to 11 years. It is designed for teachers, teacher educators in STEM, computer science teachers, curriculum designers, schools' senior leaders and policymakers.

The structure:

- The foundational structure of the framework is based on:

The **Engineering Design Process (EDP)** is a four-stage model of ask, imagine and plan, create, and improve (**Figure 3**). This was selected due to simple and clear language that is appropriate for primary children.

The **Engineering Habits of Mind** are linked to each of the four stages. Those habits that are considered *most* relevant to each stage have been aligned, as shown in **Table 1**.

Learning descriptors are then written for two **age groups – 5- to 7-year-olds (Key Stage 1) and 7- to 11-year-olds (Key Stage 2).** These describe the skills and behaviours that a teacher would plan to develop through engineering challenges and tasks.

To create the descriptors three approaches were used:

- Any descriptors that were identifiable from other learning progressions and were considered 'fit-for-purpose' were adopted. For example, the descriptor for the process of imaging, planning and 'creative problem solving' was adopted from Mass STE – namely, "to generate multiple solutions to a design problem".
- Objectives from the Design Technology Primary Curriculum informed the writing of the descriptors. It is notable that DT Technical Knowledge was not incorporated within the framework because the learning progression was focused on skills as opposed to content.
- Where no relevant matches were found, the project team created a descriptor to fulfil the purpose.

Figure 3:
EDP four-stage model

Table 1:
Foundational structure of the framework

Engineering Design Process	Engineering Habits of Mind
Ask	Problem-finding Systems thinking
Imagine and plan	Systems thinking Creative problem-solving Visualising Adapting
Create	Systems thinking Adapting Creative problem-solving
Improve	Improving Problem Finding

Framework

Purpose: Making 'things' that work and making 'things' work better

Engineering design process	Ask		Imagine and plan			
Engineering Habit of Mind	Problem-finding	Systems thinking	Systems thinking	Creative problem-solving	Visualising	Adapting
5–7 years	Ask simple question based on observations to find more information about how things work together in the world.	Explain how things work together and what can happen if there is a missing piece or link.	Draw and label a design with different parts, showing how they connect together.	Come up with more than one idea to solve a problem using a range of sources, such as cultural or historical sources.	Move ideas from the abstract (thoughts) to words and drawings (concrete).	Use an idea from one thing to design something new.
7–11 years	Ask relevant questions to better understand design problems, success criteria and constraints.	Explain systems and subsystems within products or living things, identifying patterns to understand how the different parts depend on each other.	Draw and label a design that uses a system, explaining the role of each part in the system.	Critically evaluate design choices, effectively communicating why certain ideas are better than others.	Move from abstract thoughts to words or drawings using 2D or 3D models to convey a range of ideas.	Use an idea from one thing to design something new, and critically evaluate the outcome.

Create

Systems thinking

Use components to create a product with multiple parts.

Use knowledge of how components work and interact to create a product that achieves a specific purpose.

Adapting

Take an existing product to creatively suggest how else it could be used.

Take an existing product idea to create something new and for a different user or purpose.

Creative problem-solving

Come up with ideas to solve a specific problem and choose materials to suit the purpose.

Rebuild and prototype as new ideas emerge, and critically appraise different outcomes, articulately communicating reasons for choices.

Improve

Problem-finding

Check things work by testing and evaluating.

Test that things work using a logical approach, gathering evidence to make an informed decision.

Improving

Make changes in response to an identified need or problem.

Make changes in response to a need or problem, describing and justifying the ways that the change has enhanced the design.

What have we learned?

Five cases exemplify the way in which the learning progression translated into lessons with pupils. They provide detail relating to the contexts for the lessons, which generally took around two hours to undertake. The links to the National Curriculum are provided, which demonstrate the cross-curricular way that teachers embedded the tasks through science, literacy and other subject areas.

The following lessons, with examples of children's work, can be found in the Appendix.

1. **Gingerbread man** – focus on create/creative problem solving, ages 4 to 5 years
2. **Scribble machines** – focus on create/creative problem solving, ages 8 to 10 years
3. **Hear! Hear!** – focus on imagine and plan/creative problem solving, ages 8 to 9 years
4. **Homelessness** – focus on imagine and plan/ systems thinking, ages 9 to 10 years
5. **Super suckers** – focus on imagine and plan/ systems thinking, ages 10 to 11 years

Through the commitment of teachers, each case provides further detail on how children's engineering learning develops. By examining children's work it has been possible to start to explain what success looked like for different ages or stages. **Table 3** shows an example. The main descriptor is then broken down into the skills and behaviours a child has shown when engaged in the engineering lesson.

This is a great step forward and gives confidence to the process of working with teachers to understand the learning progression in practice. Inevitably, more time is required to exemplify the full learning progression in this way.

Table 3: Extract from case study

Descriptor *to generate multiple ideas 'on the fly' when working hands-on and to evaluate and communicate various merits and drawbacks of these.*		
Success criteria		
5 to 7 years	**7 to 11 years**	**11 to 14 years**
Before this opportunity the child may have shown:	*Now the children will be supported to:*	*Next the child would be encouraged to:*
the ability to formulate ideas to solve a specific problem and choose materials to suit the purpose.	rebuild and redesign as new ideas emerge, and critically appraise different outcomes, articulately communicating reasons for choices.	add an increased complexity to designs – such as a more sophisticated way of generating movement, or integration of more advanced electronics to embed intelligence in products that respond to inputs (for example, sensors).

What challenges do we need to overcome to make engineering education thrive in mainstream primary classrooms?

The Academy's *Learning to be an Engineer: the role of school leadership* report describes how crucial school leadership vision and support is to enabling engineering to thrive within school settings. This report builds on that finding and suggests that barriers can be overcome when teachers are supported with guidance and stimulus. This cannot be taken lightly and we are far from the day where engineering education is a part of every primary classroom. To achieve this, teachers in this project have suggested the following:

Barriers

- Time is often a barrier due to the extended nature of projects that take two or three afternoon sessions to complete because of the cross-curricular and integrated nature of the experiences. Teachers reported the use of whole-day engineering 'cross-curricular', whole-day activities undertaken once a term, or open-access maker- or tinker-tables that allow children to engage with their projects more frequently, as well as curriculum planning/timetabling that allows for sequential sessions over a series of weeks.
- Not enough practical evidence to provide teachers with insight into how to embed engineering activities and lessons within the curriculum.
- Children not being emotionally ready to feel secure with things that may go wrong or may not work as they first intended it too. Teachers reported children's lack of resilience and their attitude towards not wanting to 'make mistakes'. They expressed that this was part of the engineering process but it was still something that children struggled with.
- Lack of confidence and skills were reported as holding some teachers back. They related this to knowing particular D&T skills related to cutting and joining, not having enough experience to generate cross-curricular projects/ideas or not knowing how to adapt the teacher's role to allow children to embrace the engineering design process. They commented that there are few opportunities for teachers to see this practice in action or to learn from colleagues.
- Risk management was considered to some extent, but not found to be a major barrier. Teachers explained that small group work, setting clear rules, regular exposure to equipment, as well as guidance from health and safety organisations such as CLEAPPS allowed them to mitigate risk.
- Classroom tidiness and appropriate spaces for engineering were brought up as a barrier. Keeping tables and carpets clean, table surfaces not being damaged by cutting equipment and storage of materials and children's work was limited. Some teachers talked of STEM rooms or MakerSpaces being ambitious ways to allow workbenches and equipment to be set up and accessed more easily.

Teachers identified that the new OFSTED inspection framework (DfE 2019) could open up opportunities for engineering education as it places a strong focus on ensuring children's learning is broad and balanced, as well as encouraging schools to define their own intent for the curriculum. Teachers explained that the learning undertaken within this project led to children 'learning with a purpose' and that the tasks encouraged children to show resilience and independence. One teacher suggested:

> **"We're not doing this because of school inspection regulations, we're doing it because it suits the children and our school. It's what we believe in – it's about giving children real skills that will allow them to thrive in the future."**

Enablers

To support a culture shift in schools towards engineering education in primary schools teachers considered the following factors to be relevant:

- Senior leadership explicitly endorsing and validating a creative whole-school approach to engineering and making, supported when integrated into school improvement plans.

- Teachers being given time to collaborate in and out of the school to gain support, insight and mentoring to guide innovation and critical reflection on practice, for example support from external agencies, school community parents/carers, local industry links, or STEM Ambassadors.
- Children receiving reward and recognition for progress in engineering through formative feedback communicated within and beyond school, including engaging in engineering challenges such as the Greater Manchester Engineering Challenge, school kit-box resources, RAF Fly to the Line Glider Challenge, and Fonger Challenge etc. and other programmes to promote engineering in primary schools.
- Resources being readily available and at hand for practical, creative making. Resources should go beyond just glue guns and include appropriate technical tools, such as 3D printers, hammers and nails, hand saws, and computer software packages.
- Teachers using engineering projects or challenges to link learning within existing curriculum subjects in science, technology and mathematics, for example investigating forces and motion through the creation and testing of marble runs or catapults.
- Teachers taking advantage of wider curriculum contexts and topics to stimulate engineering projects, for example using the story of the Gingerbread Man in literacy to stimulate a project on design and creating structures.
- Teachers adopting a facilitatory and co-learning approach alongside their children, for example supporting a child to develop their own designs as opposed to providing step-by-step guides.

So what now?

This report begins to shed light on what could be a learning progression for engineering in primary schools. The work is ongoing and teachers continue to trial lessons, which will help the team give further detail and align the framework to curriculum and policy requirements.

This research has shown is that there is no current learning progression aligned to the National Curriculum for England to support the teaching and learning of engineering in primary schools. This report starts to answer the key question of *how do we know children are improving when learning engineering in primary schools*? Although we are aware that more work needs to be done, it must happen at the granular detail of the framework itself, the exemplification and also at a strategic level. By working with the Academy, The University of Manchester and with partners including the Comino Foundation and schools, we seek to prompt debate and dialogue around this matter.

As other countries in our four nations move forward with explicit acknowledgement of engineering, what are the steps that we can collectively take to lobby for a more explicit approach to engineering from the primary years? There is little interest for engineering to compete with other subjects for a place in the curriculum, but instead, it could be used as a platform to invigorate and contextualise learning, making it relevant to children's lives. Our work with teachers has shown that engineering provides a way to use and apply learning, to exemplify and make subject learning real, thereby improving children's understanding and connections with the world around them.

In the short to medium term:

- Further validation, through research and classrooms trials, will enable granular exemplification of the progression framework descriptors, therefore giving teachers increased understanding and confidence of the stages of children's progression in engineering in the primary years.
- Extending the framework to pre-5-year-old and 11+ years education will mean there is greater understanding and improved transition for children into and from the primary years.
- Further review of the proposed frameworks from subject discipline specialists, in particular the D&T community, to ensure that they embed and enhance curriculum objectives and intentions.
- Invitation for wider review of the frameworks with engineering professionals and bodies, to gather insights in how the descriptors can further exemplify contemporary engineering practices.
- Exploring the transferability of the frameworks beyond England, especially to Wales and Scotland and other countries where engineering education is being established or is of interest within curriculum reform.
- Further research and evidence-based practice related to the impact on teaching and learning to be published in academic and grey-literature in the area of engineering learning progressions aligned to mainstream curriculum in England.

The longer-term aspiration will be to see how engineering learning experiences across the UK are inclusive and progressive, so that young people can move between and across countries with continuity and progression. For young people to have equal access into STEM careers and fruitful livelihoods in the engineering profession is an aspiration that many organisations hold.

This report has shed light onto how that learning can be inspired and progressive from childhood – the opportunity to capture and harness natural curiosities and passions for STEM.

Contact us

The University of Manchester's SEERIH is committed to the ongoing development of this field. It continues to support in-service teachers to collaborate with researchers in order to develop a strong practice-informed approach to innovations such as the Engineering Learning Progressions.

We invite teachers, organisations and charities to take part in and support this endeavour, in a mission to enable children to be able to make well-informed choices about their future careers in STEM.

Acknowledgements

Thanks are extended to the Royal Academy of Engineering and the Comino Foundation for their ongoing support and intellectual guidance in this field. We look forward to working closely with them to further develop this work.

With thanks to Janet Hanson, Centre for Real-World Learning (CRL) at the University of Winchester.

Teachers from the following schools were involved:

- Aspull Our Lady's Primary School
- Beech Hill Community Primary School
- Burlington Junior School
- Bury Grammar Schools
- Christ the King RC Primary School
- Elworth C of E Primary
- Gawsworth Primary School
- Kingsmead Primary School
- Nantwich Primary Academy
- Rode Heath Primary School
- St Andrew's C of E Primary School
- St Gregory's RC Primary School
- Whitegate Primary School

STEM Education Consultation Group, including: David Barlex, Helen Dobson, Sarah Earle, Janet Hanson, Karen Hill, Lea Jagendorf, Stephanie O'Donnell, Natalie Taylor, Paul Tyler, Torben Steeg.

References

Bianchi, L., (2017) *A trajectory for the development of professional leadership in science education,* Journal of Emergent Science, Winter 2016/17, Vol 12, 72–83, The Association for Science Education.

Bianchi, L., & Chippindall, J. (2016), *Tinkering – a signature pedagogy for engineering in the primary school?* The International Symposium on Engineering Education Proceedings, Sheffield, July 2016

Bianchi, L. & Chippindall, J. (2018) *Tinkering for Learning: Learning to teach engineering in the primary and KS3 classroom,* The Royal Academy of Engineering and The University of Manchester.

Bloodhound Education. Access at https://www.bloodhoundeducation.com/engage/

Bonsall, A., Bianchi, L. & Hanson, J. (2020) *Exploring learning progressions for teachers of engineering in pre-college settings: an integrative review of the literature in the last 10 years.* Journal of Research in Science and Technology Education

Department of Education (2014), Design & Technology Programmes of Study. Access at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/239041/PRIMARY_national_curriculum_-_Design_and_technology.pdf

Department of Education (2019) Education inspection framework. Access at https://www.gov.uk/government/publications/education-inspection-framework

Engineering is Elementary. Museum of Science, Boston. Access at https://eie.org/

Fonger, Nicole L., Ana Stephens, Maria Blanton, Isil Isler, Eric Knuth, and Angela Murphy Gardiner. 2018. 'Developing a Learning Progression for Curriculum, Instruction, and Student Learning: An Example from Mathematics Education'. *Cognition and Instruction* 36 (1): 30–55. https://doi.org/10.1080/07370008.2017.1392965.

Institution of Mechanical Engineers Resource Toolkits. Access at https://www.imeche.org/careers-education/supporting-teachers/resources-and-activities/stem-toolkit

Lucas, B., Hanson, J & Claxton, G (2014) *Thinking like an Engineer: implications for the education system (2014),* The Royal Academy of Engineering and the Centre for Real World Learning.

Lucas, B., Hanson, J., Bianchi, L., Chippindall, J. (2017) *Learning to be an Engineer Report,* The Royal Academy of Engineering and the Centre for Real World Learning.

Lucas, B. & Hanson, J. (2018) *Learning to be an Engineer: the role of school leadership. Royal Academy of Engineering*. Access at https://www.raeng.org.uk/publications/reports/learning-to-be-an-engineer-the-role-of-school-lead

Massachusetts Science and Technology/Engineering Curriculum 2016. Access at: https://www.doe.mass.edu/frameworks/scitech/2016-04.pdf

Next Generation Science Standards. Access at https://www.nextgenscience.org/

RAF - Fly to the Line Glider Challenge. Access at https://www.dendrite.me/competition/view/competitionid/5c5a081d08d734c830cb547e#tab:collections

Tiny Tinkering Tasks, Science & Engineering Education Research and Innovation, The University of Manchester Access at: https://seerih-innovations.org/just-good-stuff/tiny-tinkering-tasks/

Welsh Government National Curriculum https://hwb.gov.wales/curriculum-for-wales/science-and-technology/statements-of-what-matters/.

Appendix

Case study one: Gingerbread man (Gawsworth Primary School)

Engineering challenge:

Devise a means by which the gingerbread man can cross the river to escape from the fox.

Age: 4 to 5 years

EDP focus: Create

Learning objective: EHOM – Creative problem solving: Generate ideas 'on the fly' to overcome problems when working hands-on to create an object or tool.

Curriculum mapping:

Throughout the engineering challenge, many aspects of the EYFS Early Learning Goals (ELGs) were touched upon:

Communication and language development: *giving children opportunities to experience a rich language environment; to develop their confidence and skills in expressing themselves; to speak and listen in a range of situations.*

Physical development: *providing opportunities for young children to be active and interactive; to develop their co-ordination, control, and movement.*

Personal, social and emotional development: *helping children to develop a positive sense of themselves, and others; to form positive relationships and develop respect for others; to develop social skills and learn how to manage their feelings; to understand appropriate behaviour in groups; and to have confidence in their own abilities.*

Mathematics: *providing children with opportunities to develop and improve their skills in using and describing shapes, spaces, and measure.*

Understanding the world: *guiding children to make sense of their physical world and their community through opportunities to explore, observe and find out about people, places, technology and the environment.*

Expressive arts and design: *enabling children to explore and play with a wide range of media and materials, as well as providing opportunities and encouragement for sharing their thoughts, ideas and feelings through design technology..*

Success criteria aligned to the ELP

In this task the teacher organised the challenge to enable children to creatively problem solve by "*generating ideas 'on the fly' to overcome problems when working hands-on to create an object or tool.*"

The teacher took this descriptor from the 5 to 7 years framework and further developed it as shown in **Table 4**. The expectations were that children move from generating ideas to being able to critically evaluate their effectiveness using evidence from their observations during the making process.

Background

The stimulus for this activity was the traditional fairy tale, *The Gingerbread Man*. Having familiarised the children with the story, the teacher developed fake 'CCTV footage' of several gingerbread men rampaging through the Reception classroom to provide the children with a stimulating 'real-world' context for their learning. This short video was created using the free digital application, *FXGuru*, that is available for use on tablet and phone devices. Children also received a fake letter, written by the gingerbread man, asking for their help.

Teacher's role: The teacher's role in this challenge was to facilitate the children's learning by providing a set of carefully chosen pre-activities to provide a foundation of knowledge to aid their design and build decisions. These included the following science sessions:

Table 4

Learning intention *Generating ideas 'on the fly' to overcome problems when working hands-on to create an object or tool.*		
Success criteria linked to age group		
4 to 5 years	**5 to 7 years**	**7 to 11 years**
Before this opportunity the child may have shown:	*Now the children will be supported to:*	*Next the child would be encouraged to:*
the ability to generate a limited range of ideas when attempting to overcome a problem. These ideas may be random and not linked in any way.	formulate ideas to solve a specific problem and choose materials to suit the purpose.	rebuild and redesign as new ideas emerge, and critically appraise different outcomes, articulately communicating reasons for choices.

- Floating and sinking: children were able to apply their knowledge of which objects would float or sink to the design of their device.
- Sorting and classifying: in small groups, children sorted and classified materials based on their waterproofing properties.

In the imagine and plan task, the teacher took on the role of observer, allowing the children to be much more independent. Children were given the opportunity to share their thoughts and ideas in group discussion sessions (circle time).

Session structure

The word '*means*' was chosen deliberately to allow the children to think freely about what structure or innovation they were going to create. This was a deliberate move from previous lessons where they had been told to 'design a bridge' or 'build a boat'. By not prescribing the type of structure, the children were able to think without constraint. Through dialogue, they were encouraged to recall the floating and sinking activities to maintain a focus on the functionality and purpose of their models, rather than the aesthetics.

The making task was set as part of a home learning challenge. This meant that adult support and intervention could not be monitored; however parents were encouraged to allow their children to take the lead.

Parents/carers interpreted the challenge in different ways – some guiding the choice of design or the extent to which the child worked independently. Children were given access to a range of different resources dependent upon what materials families had readily available at home.

Outputs:

Photographic and written evidence demonstrates that children drew on the teacher's initial input and were able to develop a series of imaginative designs.

- Grace came up with several different ways to cross the river before deciding on a hot air balloon.
- Ideas included giant slides, zip wires, rafts, boats, bridges, and a space rocket.
- Nancy decided that the gingerbread man would travel across the river on a dinosaur's back.

It was evident that several children had applied their knowledge of materials to produce their designs and had used the engineering design process to test and improve their products.

Ideas included giant slides, zip wires, rafts, boats, bridges, and a space rocket.

Nancy decided that the gingerbread man would travel across the river on a dinosaur's back.

Evelyn's challenge

Evelyn's parent explained their daughter's approach:

"Evelyn decided that she wanted to build a raft out of sticks to help the gingerbread man cross the river safely. She did a design on paper and then went out to collect sticks. She chopped the sticks with help from daddy and then tied them together with string. She tested the raft out with horses, and it worked! Next, she added a leaf and daisy deck and then a cardboard shelter with windows. Evelyn then added two plastic bottles to the base of the raft to make it more buoyant. Evelyn tested the raft out in her paddling pool, and it worked really well. All in all, a wonderful project."

Theo's challenge

Theo embraced the objective by constructing boats made from several different materials. His parents explained:

"Theo made three different boats – one from egg boxes; one from lollipop sticks and one from woodland sticks. We investigated which would be best for the gingerbread man to use to cross the river. Theo said the woodland sticks one would be the best because – 'it's the strongest'. He was eager to find out. Theo was disappointed when the egg box one got very wet and fell apart but realised the cardboard wasn't waterproof. The lollipop one lost a stick and floated a little before sinking. In the end, his prediction was of course correct! The stick boat was strong and floated well! A great boat for the gingerbread man."

Children demonstrated that they have moved from simply making a model to thinking about different solutions and how the materials chosen will help to solve the problem.

Evelyn added several improvements to her raft

Both children have demonstrated that they were beginning to generate new ideas as they were building their products, particularly Evelyn who added several improvements to her raft.

Case study two: Scribble machines (Whitegate CE Primary School)

Engineering challenge: Create a step-by-step guide communicating how to construct a scribbling machine demonstrating clear understanding of how the components fit together.

Age: 8 to 10 years

EDP focus: Create

Learning objective: EHOM Creative Problem Solving: to generate multiple ideas 'on the fly' when working hands-on and to evaluate and communicate various merits/drawbacks of these.

Curriculum mapping:

Science: *electricity – apply knowledge of electrical components to make a scribbling machine.*

Literacy: *instructional writing – discuss and record ideas; identify audience and purpose, selecting appropriate form; use simple organisational devices such as headings and subheadings.*

Design technology: *technical knowledge – understand and use electrical systems in products (for example series circuits incorporating motors).*

Success criteria aligned to the ELP

In this task, the teacher organised the challenge to allow the children to creatively problem solve by "*generating multiple ideas 'on the fly' when working hands-on and to evaluate and communicate various merits/drawbacks of these.*"

The teacher took this descriptor from the KS2 Framework and further developed it as shown in **Table 5**. The expectations were that children move from generating ideas to being able to critically evaluate their effectiveness using evidence from their observations during the making process.

Background

This session was the culmination of a series of science lessons about electricity and was designed to assess the children's understanding of circuits and their ability to apply that knowledge to a different context.

The lesson focused on creative problem solving. With clear links to literacy, the children were required to create an instructional guide for peers based on their own practical experiences.

This provided opportunity to inspire purposeful writing, especially for more reluctant writers.

Teacher's role

Facilitator and questioner: collaborating with the children, being side-by-side with them to stimulate dialogue about choices of materials and offering assistance if necessary, for example: helping the children to connect the motor to the battery and encouraging them to observe the difference in motion depending on the positioning of the propeller.

Later in the lesson, the teacher modelled the process of instructional writing to develop the children's use, precision and sophistication of language within the text.

Table 5

Learning intention *to generate multiple ideas 'on the fly' when working hands-on and to evaluate and communicate various merits/drawbacks of these.*		
Success criteria		
5 to-7 years	**7 to 11 years**	**11 to 14 years**
Before this opportunity the child may have shown:	***Now the children will be supported to:***	*Next the child would be encouraged to:*
the ability to come up with ideas to solve a specific problem and choose materials to suit the purpose.	**rebuild and prototype as new ideas emerge, and critically appraise different outcomes, articulately communicating reasons for choices.**	add an increased complexity to designs – for example. a more sophisticated way of generating movement, or integration of more advanced electronics to embed intelligence in products that respond to inputs [(or example, sensors).

Lesson structure

Design: *to focus the children on the creative problem-solving process – to think how different parts would fit together and what purpose each part had.*

Children were given access to a range of components to make their scribbling machine, such as motor, wires, sticky tape, and recycled containers. Before construction, they looked at and discussed the components on offer, talking about how they would fit together before selecting. Within the task they individually drew and labelled a diagram, indicating what role each part of the machine would play in the design.

Prompt questions used to ask the children included:

- What kind of container will you use?
- How will you fix your motor to the container?
- How will you modify your motor to make your contraption move?
- Where will you position your pens?

Make: *to experience their ideas in reality, enabling them to work in a hands-on manner and persevere with evaluating and communicating what's happening.*

Children worked in pairs to construct their scribbling machines. They discussed how to bring their designs together, and were given time to test out, refine and improve their machines. They were given freedom to make, test and alter their original designs based on their observations during the make.

Evaluate: *to reflect on the creative problem-solving process, and give opportunity for whole class reflective discussions, including teacher formative feedback on next step learning.*

A class discussion focused on encouraging the children to talk in pairs and then as a whole class about suggestions for how their scribbling machines might be adapted and improved to do more refined or different things, for example, how could it make bigger and smaller circles? How could it travel slower and more smoothly? What different patterns could it make?

Children suggested a range of ideas, highlighting aspects of their own and other machines that they found interesting and offered suggestions, including adding a switch or some sensors to control when the machine was powered, to using different materials to draw with.

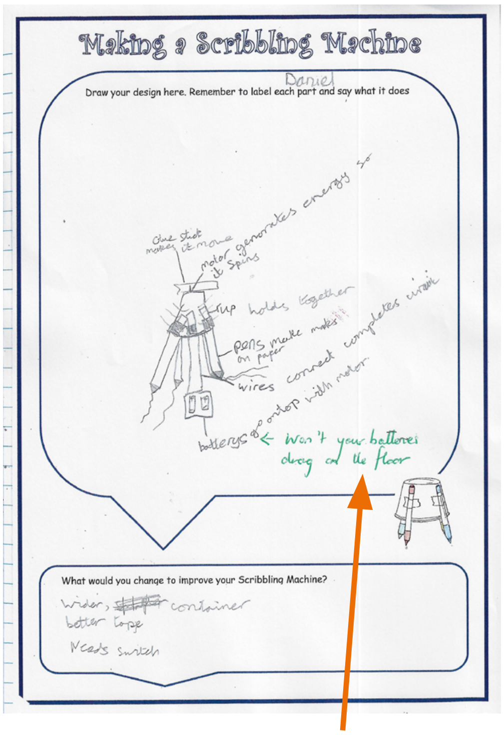
Communicate: *to inspire children to apply their literacy skills, by offering a purposeful and relevant scenario to instructional writing.*

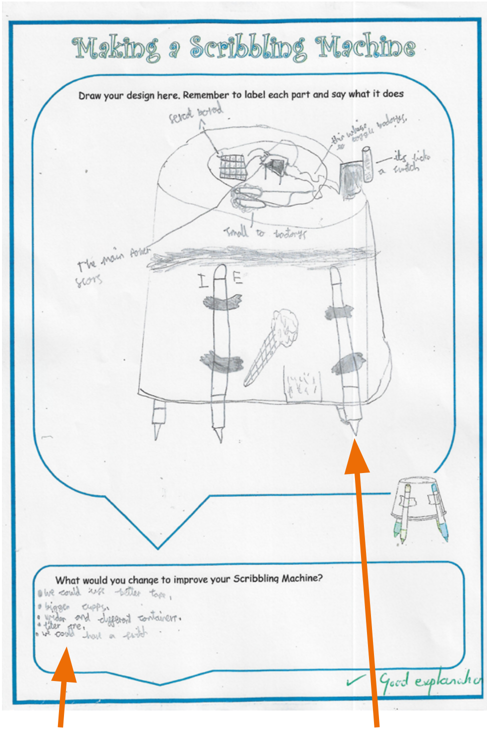
Children produced an instructional guide to create a scribbling machine. This was done initially as whole-class modelled writing activity, during which time the teacher involved and encouraged more reluctant writers to share their ideas.

They had some experience of instructional writing before. This applied opportunity brought out a greater level of precision and sophistication in vocabulary, for example the use of imperative verbs. Each child then worked independently on this task.

Whitegate Primary School pupils engaged in the challenge

Outputs

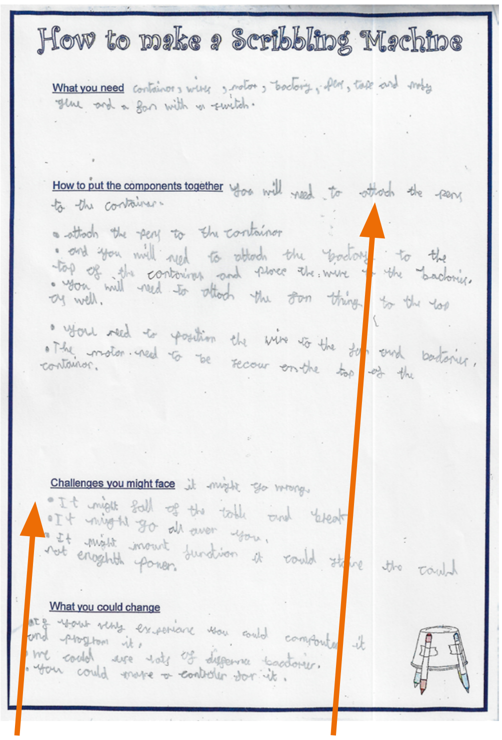


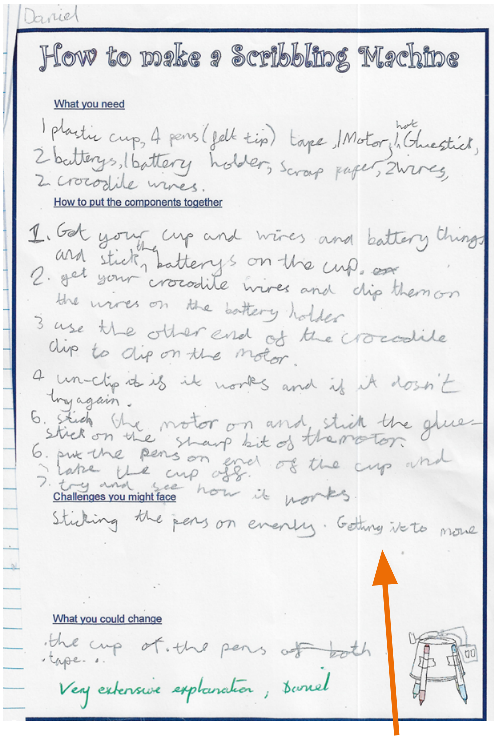


Teacher feedback encouraging further thought on the design.

Further information about adaptations added after first opportunity to make.

Detail shows methods of fixing and also how the motor would be connected.





Structure provided to scaffold children's responses in order to prioritise effort on the precision of vocabulary.

Use of imperative verbs, such as using 'attach' and 'unclip' as opposed 'put' or 'get'.

Demonstration of the quality and detail of text given through this task from reluctant writers.

Case study three: Hear! Hear! (Kingsmead Primary School)

Engineering challenge: Imagine and design an outer ear (pinna) to improve hearing for humans.

Age: 8 to 9 years

EDP focus: Imagine and plan

Learning objective: EHOM Creative problem solving: *Generate and evaluate multiple ideas to choose optimal solutions. Communicate ideas effectively with others.*

Curriculum mapping:

Science: sound – to recognise that vibrations from sounds travel through a medium to the ear; to explore how different shapes affect how sound is captured.

Literacy: spoken language – to use spoken language to develop understanding through speculating, hypothesising, imagining and exploring ideas.

Design technology: design – to generate develop, model and communicate ideas through discussion and annotated sketches.

Success criteria aligned to the ELP

In this task the teacher organised the challenge to allow the children to creatively problem solve by "*generating and evaluating multiple ideas to choose optimal solutions, communicating ideas effectively with others*".

The teacher took this descriptor from the KS2 Framework and further developed it as shown in **Table 6**. The expectations were that children would move from merely generating multiple ideas to being able to critically appraise and improve their original designs using knowledge gained during the project. It would be desirable if they developed their collaborative skills, discussing ideas well and building on their original thinking to come to agreement over designs without needing teacher intervention – pairings were mixed ability and mixed gender.

Background

Initially children had a series of science lessons to introduce the topic of sound. In these, the children learned about how sound travels through different media and how vibrations relate to volume and pitch. They were then engaged in investigating - how might changing the shape of the outer ear affect how well an animal hears?

The teacher selected the stimulus of the non-fiction book *What if you had Animal Ears* by Sandra Markel, which shows examples of different animals and discusses the shape of their ears and benefits of each. The teacher read this to the children, introducing ideas about animals with acute hearing and also those whose ears enable them to regulate temperature (losing heat through their ears, or by flapping their pinnae).

Lesson structure

Children were then challenged to imagine and design a set of outer ears for humans that would improve hearing quality. Children were encouraged to use existing knowledge of sound and ear shape to inform their decisions.

Children worked in pairs with a planning guide to support them to draw and label diagrams of their design. They were told that this would become a 3D model, and that they needed to list the suggested materials they would use for the ears, from choices

Table 6

Learning intention *to generate and evaluate multiple ideas to choose optimal solutions. Communicate ideas effectively with others*		
Success criteria		
5 to 7 years	**7 to 11 years**	**11 to 14 years**
Before this opportunity the child may have shown:	***Now the children will be supported to:***	*Next the child would be encouraged to:*
the ability to generate an increasing number of ideas to solve a problem.	**critically evaluate design choices; effectively communicate their rationale and adjust plans as necessary to improve final output.**	develop a greater understanding of the user experience by analysing the target audience in depth and allowing this to inform their design decisions.

such as card, paper, foam board, plastic board, bubble wrap, fur and foil.

The teacher encouraged the children to verbally share their ideas, asking questions to explain how their ear shape and choice of material would fit the challenge brief. She encouraged them to use 'because' within their statement.

Children's ideas included:

"I have chosen large oval shaped ears because they have a big surface area to catch sound."

"I have chosen rotating ears, because this will allow noises to be heard from different directions."

"I have chosen bubble wrap because it will trap the sound waves better."

"I have chosen foil as one of my materials because this will allow sound to bounce off and into the ear canal."

After their initial ideas were generated and shared, the children were then given additional time in their pairs to further discuss and revise their plans if necessary.

This allowed them to critically appraise their ideas with their partner using any new information and, as a result, many groups made adjustments – either choosing just one material or in some cases two, and rejecting fur as an option.

Teacher's role

Observer, listener and questioner: encouraging children into conversation about their designs, posing questions to encourage them to think about detail related to materials, and how their design linked to what they had learned about sound. The teacher was able to hear and address misconceptions in science knowledge and also encourage alternative or more ideas.

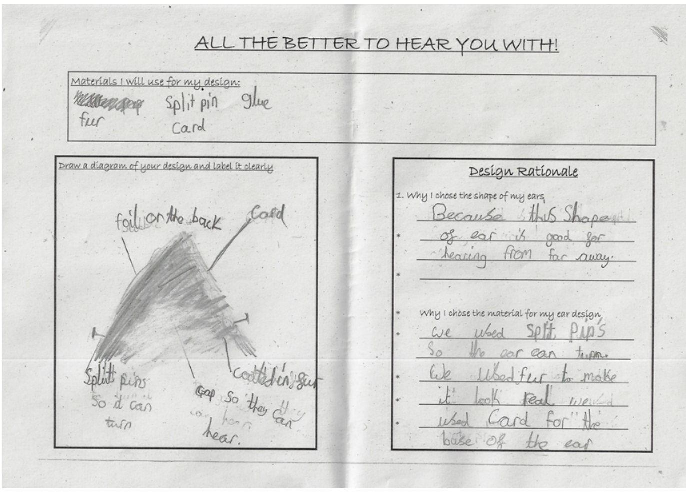
For example:

Many children initially chose fur as a material for their designs; however, it became clear that their decision was because "*lots of animals have furry ears*" rather than any engineering purpose.

The teacher was able to pick up on this and discuss the benefits of furry ears and establish that these were aligned more to aesthetic and thermal qualities rather than improving hearing, which was the aim of the challenge.

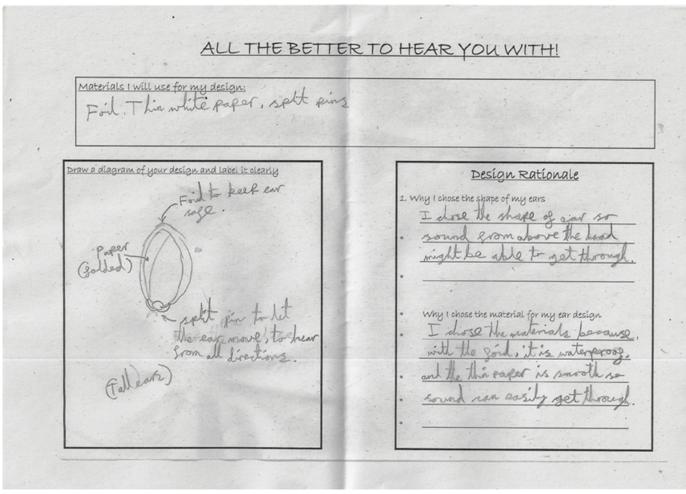
Outputs

Children used their knowledge of sound and how ear shape influenced animal's hearing to produce a range of ear-shapes to improve human hearing. These included increased surface area to catch more sound; pointed shapes to reduce background noise; long oval shapes to catch sound from above and rotating ears to enable hearing from all directions.



Children generating different ideas to solve a problem. They use diagrams and text to communicate their ideas.

To develop this further the child would need to critically evaluate design choices and communicate their rationale.



In this example, the child is showing critical appraisal of their ideas and linking their reasoning to their scientific knowledge and understanding.

Case study four: Homelessness (Rode Heath Primary School)

Engineering challenge: Generate ideas for a product that will help solve a problem for a homeless person. Communicate these ideas through a labelled drawing which explains how the different components and how they work.

Age: 9 to 10 years

EDP focus: Imagine and plan

Learning objective: EHOM systems thinking: *to illustrate (for example through labelling) an object or tools' subsystems and components and how these interact*

Curriculum mapping:

Science: properties of materials – to apply knowledge of properties of materials to design product for a homeless person.

Literacy: spoken language – to gain, maintain and monitor the interest of the listener by delivering well-structured explanations.

Design technology: to generate, develop, model, and communicate ideas through talking, drawing, templates, mock-ups and, where appropriate, information and communication technology.

Success criteria aligned to the ELP

In the main task, the teacher challenged the children's systems thinking skills by *"illustrating (for example through labelling) an object or tools' subsystems and components and how these interact"*.

The teacher took this descriptor from the KS2 Framework and further developed it as shown in **Table 7**. The expectations were that children would move from simply recognising the different components of a product to being able to demonstrate a clear understanding of the function that each component has.

Background

This challenge was started by engaging the children in a '*problem finding*' session where they were introduced to the topic of homelessness and given some facts to think about, such as:

- Homelessness is when someone has nowhere to live or no permanent place to call home.
- According to Shelter, 320,000 people in the UK are homeless.
- This represents 1 in 200 of the population.
- More than 9,000 people in the UK sleep rough every night.

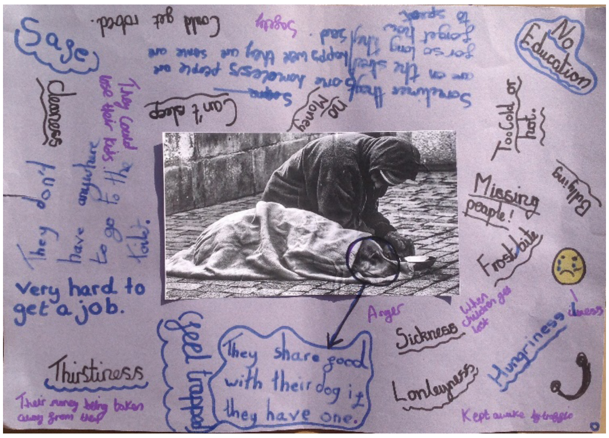
In groups of three or four, children were then provided with a photograph, depicting an aspect of homelessness, and asked to write down any problems they thought this person might face.

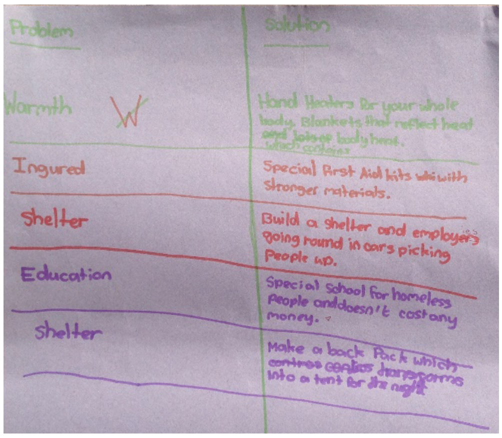
Having talked about and shared ideas in their groups for around 10 minutes, they were then tasked with listing some of the problems that they discussed and to suggest potential solutions that could be taken by communities or the people themselves.

Children refining their ideas by identifying problems and generating potential solutions through group discussion.

Table 7

Learning intention *to illustrate (for example through labelling) an object or tools' subsystems and components and how these interact.*		
	Success criteria	
5 to 7 years	**7 to 11 years**	**11 to 14 years**
Before this opportunity, the child may have shown:	***Now the children will be supported to:***	*Next the child would be encouraged to:*
the ability to produce a basic illustration which shows an understanding of the different components through the labelling.	**improve the sophistication of their drawings whilst understanding and noting how the different components work together through more detailed labelling.**	demonstrate a clear understanding of how the properties of materials chosen and the performance of structural elements have been used to achieve functioning solutions.





Children's 'thought-shower' responses to a photograph stimulating them to think about problems that may be faced by homeless people.

Teacher's role

Facilitator and questioner: initially setting the scene by providing basic facts and figures about homelessness; followed by visiting individual groups and listening as ideas were formulated.

Lesson structure

Imagine: *to focus the children to begin the imagine and plan process – thinking about which of their initial ideas might provide the best solution for homeless people.*

The lesson began with a visit from a pupil's parent who worked directly with homeless groups local to the school. This gave the children a chance to talk about and 'validate' their product ideas at a very early stage in their development as they had access to an 'expert'.

The involvement of an external visitor enabled the challenge to be authentic and allow children access to learn more about the topic by asking relevant questions.

Plan: Following a brief presentation from the visitor and Q&A session, the children chose one of the solutions from their group list and worked as an individual or in pairs to further develop their idea. They were given prompt questions to support this process, including:

- Which problem is your product designed to solve?
- How does it work?
- Is this feasible as a product? Could it be made? Do you need to make any changes?

The children drew sketches of their products, labelling the different components and explaining their functionality. Both girls and boys were engaged throughout the task, and several pupils independently developed their product ideas more fully at home.

Communicate: *to develop presentation and language skills by encouraging children to share their ideas in front of an audience.*

Having visualised their designs, children were given the opportunity to present their ideas and receive feedback from the rest of the class.

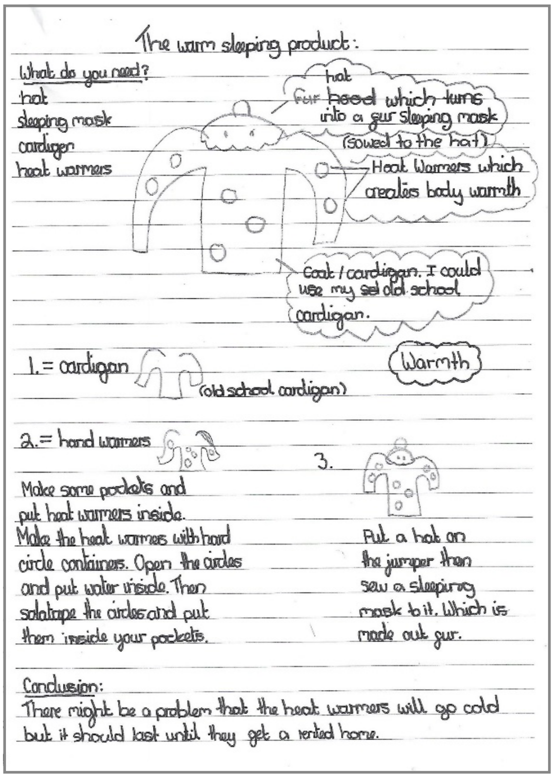
A short amount of time was allocated to allow groups to prepare their presentation. Some groups elected to produce a PowerPoint, while others talked with an enlarged version of their drawings.

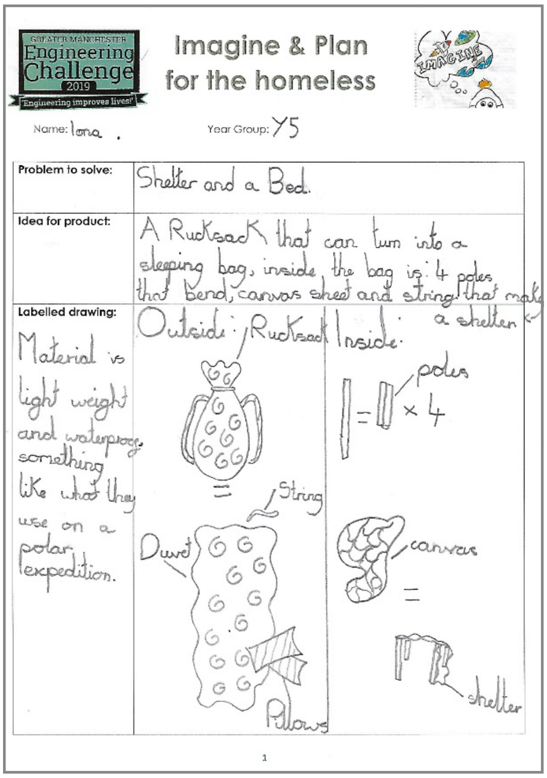
The relevant and purposeful nature of this task had a noticeable impact on the confidence and clarity with which the children spoke.

They demonstrated a clear ownership and passion for a product that they had designed themselves to solve a real problem.

Nine- and ten-year-old children engaged in discussing the challenge with an external expert.

Outputs





Children illustrate, through labelling, the features of their product and how they come together. They also show more than simply labelling the design, but considering the role each component part plays in the design.

Here the child identifies the rucksack (the tool) and the subsystems within the design. Using diagrams to visualise and illustrate how the system works. The child communicates the multi-functionality of the design, beyond just labelling.

Children showing that they are seeking to identify the limitations of their design.

Case study five: Super suckers (Burlington Junior School)

Engineering challenge: How can we now use what we know about hair dryers to design and build our own hand-held vacuum cleaner that will suck up small pieces of paper?

Age: 10 to 11 years

EDP focus: Imagine and plan, create

Learning objective: EHOM systems thinking: *to construct an object or tool requiring successful interaction between components and subsystems.*

Curriculum mapping:

Science: electricity Y6 – to compare and give reasons for variations in how components function, including the brightness of bulbs, the loudness of buzzers and the on/off position of switches.

Literacy: spoken language – to understand and use key technical vocabulary.

Design technology:

- Design – generate, develop, model and communicate their ideas through discussion, annotated sketches, cross-sectional and exploded diagrams, prototypes.
- Make – select from and use a wider range of materials and components.
- Evaluate – evaluate their ideas and products against their own design criteria and consider the views of others to improve their work.
- Technical Knowledge – understand and use electrical systems in their products.

Success criteria aligned to the ELP

In this task, the teacher challenge the children to systems think by "*constructing an object or tool requiring successful interaction between components and subsystems*". They used the context of how hairdryers work to stimulate the task and looked at the different parts of a hair dryer to establish their function.

The teacher took this descriptor from the KS2 Framework and further developed it as shown in **Table 8**. The expectations were that children moved from merely understanding how parts within a particular system function and interact with each other to using that knowledge to create a different working product. They also had the opportunity to develop their communication and problem solving skills, discussing ideas well and building on their original thinking, with the teacher acting only as a facilitator – groups were mixed ability and mixed gender.

Background

This session built on the children's existing work on electricity and how different components function.

Teacher's role

Facilitator, observer, questioner: to observe and listen to children's conversations, asking questions to move on learning when appropriate, for example, *how would you make the fan spin in the opposite direction*?

Lesson structure

Systems seek: The teacher dismantled a hair dryer and encouraged the children to look at and identify the different parts. She asked questions to encourage the children to consider the function, confirming their understanding of different components.

Table 8

Learning intention *to construct an object or tool requiring successful interaction between components and subsystems.*		
Success criteria		
5 to 7 years	**7 to 11 years**	**11 to 14 years**
Before this opportunity the child may have shown:	***Now the children will be supported to:***	*Next the child would be encouraged to:*
use components to create a product with multiple parts	use knowledge of how components work and interact to create a product that achieves a specific purpose	select from and use a wider, more complex range of materials, components and ingredients, taking into account their properties

After this, the children worked in smaller groups to look more carefully at the hair dryer that had been opened up.

The teacher acted as facilitator and asked children to comment on the mechanisms. For many, this was the first opportunity to see inside a hair dryer.

Key questions included:

- Which parts are necessary for the hair dryer to work?
- What is the fan for and where is it placed?
- Where is the motor? What is its function?
- What is the purpose of the heating element?

From this, teacher and children discussed the various elements and their function. The children were initially tasked to make their own fan that would blow air when attached to a motor.

They were provided with a wide selection of materials including a plastic bottles, cardboard, motors and batteries. From these, they chose materials for creating the fan and used their electrical knowledge to put their own circuits together.

They needed some encouragement to support tinkering and resilience. They were also encouraged to compare the effectiveness of different design shapes and sizes by the force of air movement felt or created when pointed at an object, in order to identify the best design.

They started to make a connection between the hairdryer blowing and a hoover sucking, and wondered how the change of function was achieved.

System test: They were then challenged to produce the reverse effect and create vacuum cleaners in small groups. They tinkered, including turning the fan around, and eventually changed the wiring to create suction.

These were then tested on the 'confetti' from hole-punchers. Children exhibited considerable perseverance in this task to make the vacuum suck effectively.

Children were given time to observe the success of other groups' designs and revise their own if necessary. This allowed them to critically appraise their ideas with their partners using new information that they had gained. A measure of success was how many pieces of 'confetti' were sucked up.

They spent two afternoon sessions on the task and demonstrated a determination to achieve their goals, staying noticeably more focused than for other lessons. They were highly motivated and repeatedly asked when they would be participating in the task again, so as to complete the challenge.

Outputs:

Children used their knowledge of electricity and how motors worked to produce a range of different fans. Discussion and reflection was integral to the full learning process, with opportunities for children to think-share and question each other and the teacher.

Children said:

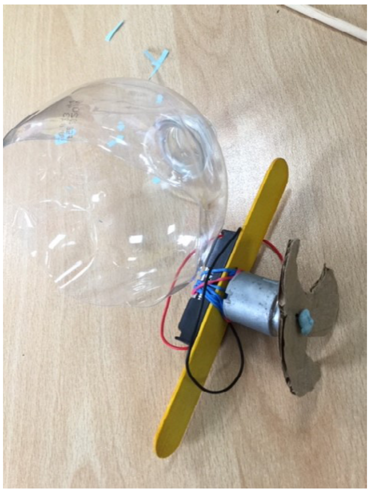
"I was really surprised by what is inside a hair dryer. I enjoyed tinkering to make ours and then to make it work well. I was surprised that changing the wiring made it change from blowing to suction. I liked doing an engineering activity in school."

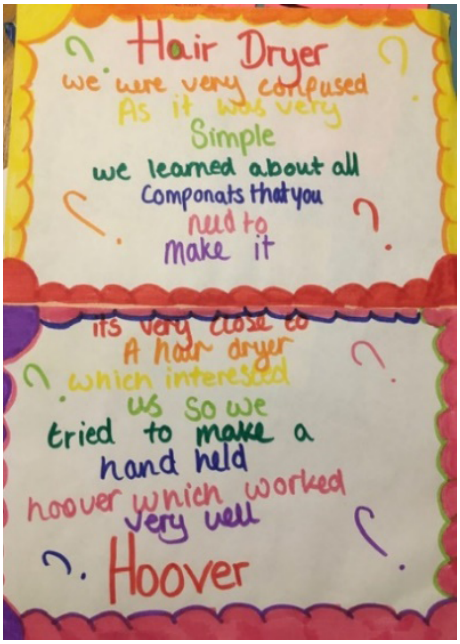
"I like puzzling things out and really enjoying trying to work out how to make it go."

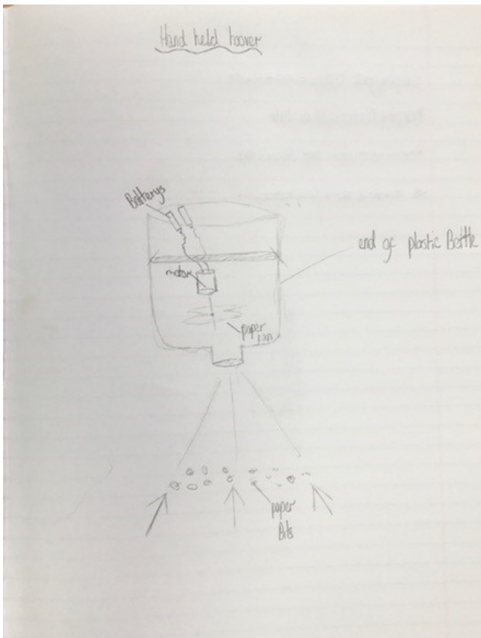
"The way that we collaborated and tinkered with it worked really well. We enjoyed testing our engineering skills."

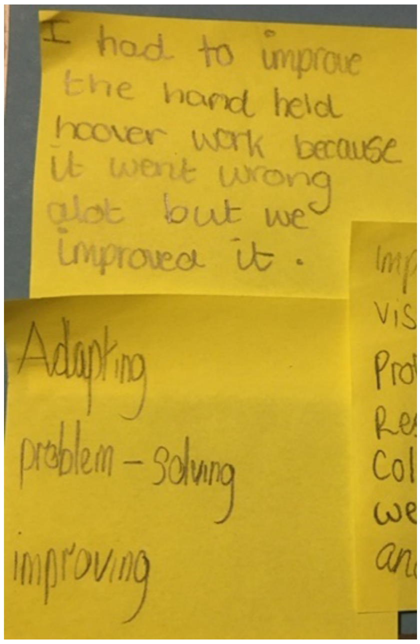
"We had to be very reflective and resilient because it didn't work first time."

Nine- and ten-year-old children engaged in discussing the challenge with an external expert.









This demonstrates an understanding of the different components required and how they fit together.

Royal Academy of Engineering

The Royal Academy of Engineering is harnessing the power of engineering to build a sustainable society and an inclusive economy that works for everyone.

In collaboration with our Fellows and partners, we're growing talent and developing skills for the future, driving innovation and building global partnerships, and influencing policy and engaging the public.

Together we're working to tackle the greatest challenges of our age.

What we do

Talent & diversity

We're growing talent by training, supporting, mentoring and funding the most talented and creative researchers, innovators and leaders from across the engineering profession.

We're developing skills for the future by identifying the challenges of an ever-changing world and developing the skills and approaches we need to build a resilient and diverse engineering profession.

Innovation

We're driving innovation by investing in some of the country's most creative and exciting engineering ideas and businesses.

We're building global partnerships that bring the world's best engineers from industry, entrepreneurship and academia together to collaborate on creative innovations that address the greatest global challenges of our age.

Policy & engagement

We're influencing policy through the National Engineering Policy Centre – providing independent expert support to policymakers on issues of importance.

We're engaging the public by opening their eyes to the wonders of engineering and inspiring young people to become the next generation of engineers.

Royal Academy of Engineering
Prince Philip House
3 Carlton House Terrace
London SW1Y 5DG

Tel: +44 (0)20 7766 0600
www.raeng.org.uk
Registered charity number 293074